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מספר: Number 147473
תאריך: Date 03-01-2002 הוקדם/נדחה Ante/Post-dated

בקשה לפטנט
Application for Patent

אני, (שם המבקש, מענו ולגבי גוף מאוגד - מקום התאגדותו)
I (name and address of applicant, and in case of body corporate, place of incorporation)

Nova Measuring Instruments Ltd., Weitzmann Scientific Park, P.O.B. 266, Rehovot 76100

נובה מכשירי מדידה בע"מ
חברה ישראלית, מוייצמן פארק למדע, ת"ד 266, רחובות 76100

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בעברית (Hebrew)
שיפור איכות תמונה במערכות הדמיה קוהרנטית

באנגלית (English)
Image Enhancement of Coherent Imaging Systems

Hereby apply for a patent to be granted in respect thereof
מבקש בזאת ינתן לי עליה פטנט

* בקשת חלוקה Appl. Of Div.	*בקשת פטנט מוסף Appl. for Patent Add.	* דרישת דין קדימה Priority Claim		
מבקשת פטנט to Patent/Appl No. .... מס' dated .... מיום	* לבקשה/לפטנט to Patent/Appl. No. .... מס' dated. .... מיום	מספר/סימן Number/Mark	תאריך Date	מדינת האגוד Convention Country
*יפוי כח: כללי/מיוחד רצ"ב/עוד יוגש P.O.A.: general/indiv/-attached/to be filed later Filed in case הוגש בענין				
המען למסירת מסמכים לישראל Address for services in Israel: נובה מכשירי מדידה בע"מ חברה ישראלית, מוייצמן פארק למדע, ת"ד 266, רחובות 76100				
חתימת המבקש Signature of Applicant Moshe FINAROV, Director of Technology		היום 03 This לחודש 01 Month שנת 2002 Year		
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Image Enhancement of Coherent Imaging Systems

שיפור איכות תמונה במערכות הדמיה קוהרנטית

Optical inspection and metrology systems can be based on coherent or incoherent illumination. Systems for spatial analysis of surfaces can be based on scanning spot image generation or on imaging of the required field of view. In order do achieve artifact-free coherent imaging, good spatial filtering of the light source is required. This reduces speckle effects due to the light source. In addition, artifacts are caused by numerical aperture (NA) limitations. A finite numerical aperture has the effect of a low-pass filter on the spatial frequencies of the image. This causes oscillatory edge-ringing effects in the image (also known as the Gibbs effect) due to the effect of convolution of the Fourier transform of the system aperture with the image. This effect is directly related to the size of the NA of the system.

In this disclosure we present a number of techniques that enable reduction of the edge-ringing effects caused by the limitations of finite Numerical Aperture.

The low-pass effect of the limited NA of a coherent system removes high angle spatial frequencies from the image of the object. The limiting frequency of the edge of the NA for a system with wavelength λ is:

$$K_x = K_o * tg\alpha \approx 2 * \pi / \lambda * NA$$ (see **Fig. 1**)

The X-axis component at the object plane of the Fourier transform of a square aperture is:

$$G(X) = 1/(2*\pi) * \sin(K_x*X)/(K_x*X)$$

where G(X) is also the diffraction limited point spread function of the system. The image obtained at the output of the system is:

$$\mathbf{I(X) = F(X) \otimes G(X)},$$

where **F** is convolved with **G**. (See **Fig. 2**)

A finite aperture causes ringing containing a pattern mainly due to the angular frequency immediately outside the numerical aperture. The detailed characteristics of the ringing depend on the exact shape of the aperture. The result of the finite aperture is an oscillatory artifact in the image of pitch:

$$Pitch = 2 * \pi / Kx = \lambda / NA$$

A well-known effect of periodic objects in optical systems is the self-imaging effect at out-of-focus conditions. This is known as the Talbot effect, which takes place near focus at distances within the Fresnel regime. The Talbot distance associated with a pitch D is:

$$Z_T = 2 * D^2 / \lambda$$

Under defocus conditions an infinite grating undergoes self-imaging at defocus distances of $n * Z_T$, where n is an integer. At offset distances of $Z_T/2$ the image is a negative one, i.e. at distances of $(n+½) * Z_T$. In the present case the Talbot distance associated with the ringing pitch is:

$$Z_T = 2 * D^2 / \lambda = 2 * \lambda / NA^2$$

The ringing undergoes an effect similar to self-imaging but with limitations caused by the finite extent of the ringing oscillations and the small higher spatial frequency content. At half Z_T distance this effect causes formation of an image with negative contrast oscillations. It should be noted that the negative contrast effect is more accurate further away from the edges that cause the oscillations. At the edge itself the "overshoot" of the intensity undergoes a lateral shift but does not change contrast. This overshoot is due to the central lobe of the aperture Fourier transform G(X); the lateral change of the overshoot is directly associated with the change in the diffraction limited point spread function of the system due to defocus.

In the present invention we utilize the negative contrast effect to average two images taken at two different focal positions in order to cancel out most of the ringing effects of the image (see **Figs. 3 and 4**). These images can be added coherently or incoherently to achieve a similar effect. Moreover, this technique works for any two images taken with a relative defocus between them of $Z_T/2$. Thus the technique is applicable even in the case of inaccuracy in the initial focus. Additionally it becomes apparent that at a defocus of $Z_T/4$ from exact focus the image is intermediate between the two anti-phase-ringing images. The image in this case is equivalent to the average of the two images at zero and $Z_T/2$ defocus.

Fig. 5 shows a 20 micron square object imaged through a 0.25 NA system at wavelength of 800nm. **Fig. 6** shows the effect of the averaging technique in smoothing the ringing effects within central region of the square. The vertical axis of the 3D plot is the intensity at the image plane.

The focal depth of a coherent system is known in the literature to be:

$Z_f = \lambda / 2 / NA^2$

Therefore the defocus required to smooth the ringing is of the order of the focal depth. In this case the diffraction limited point spread function of the system grows by a factor of order 2 in relation to the in-focus condition.

It should be noted that the above description is applicable for any simple shape of finite aperture. The square aperture was chosen as an example.

An additional technique is based on variation of the NA of the system. Different numerical apertures result in different typical ringing pitches. Averaging a series of images results in smoothing of the oscillations. Each image is averaged with weighting calculated from the specific NA. These images can be added coherently or incoherently to achieve a similar effect. The effect can be analyzed as a beating effect as follows. Reducing the NA so that the number of oscillations in a given area is reduced by one, results in an anti-phase condition at the center of the area. This second image in effect "cancels" the oscillation at the center of the area. Including an image with reduced NA such that the number of oscillations is reduce by two causes beating at two locations within the area in relation to the original image. In general, adding a series of images at reduced NA such that each one causes a smaller number of oscillations, gives a reduced level of ringing in the final image. In this case the penalty, in the form of reduced lateral resolution of the image due to the reduced NA, is larger than that of the images for the above defocus technique. This is due to the fact that for small areas the number of oscillations is small and the NA reduction steps are relatively large. For example a 35 micron wide stripe contains 7 oscillations when imaged through a NA=0.25 system at wavelength of 800nm. In **Fig.** 7 five NA steps are averaged. The range of NA in this case is between 0.25 and 0.14. The result has been lowered by 15% in the graph for clarity.

This NA effect can also be achieved, to a similar degree, by shaping the aperture of the system to include segments of varying NA. The different segments are place symmetrically about the optical axis and the effective signals are inherently averaged coherently. For example a "flower-shaped" aperture can be used as shown in **Fig. 8a**. Another example is useful for images that consist mainly of squares (as illustrated in **Fig. 8b**), rectangles and orthogonal lines along the main x-y axes of the optical system. In this case placing a square aperture rotated 45 degrees to the axis, results in reduced amplitude of the ringing.

The image itself can also be directly processed, based on the knowledge of the physical parameters of the system. For example, it can be spatially filtered with a notch filter of pitch: Pitch = λ / NA. An additional method can be to analyze a predefined calibration object with the system and record the edge response at the image. An inverse filter can be formed from this edge response and it can be used to process images to achieve reduction of the ringing as well as the overshoot effects at the edges. This calibration object can be analyzed separately and the edge response retained for later use or the predefined object can be included in the optical system and imaged concurrently with the object that the system is examining, preferably on the same imaging sensor, e.g. a CCD camera. In one embodiment the object under examination is imaged on part of the CCD device and the calibration object is imaged on another part of the CCD device.

Those skilled in the art will readily appreciate that many modifications and changes may be applied to the invention as hereinbefore exemplified without departing from its scope, as defined in and by the appended claims. For example, combination of both techniques of Image Enhancement may be performed in the method of coherent imaging or in coherent imaging system.

CLAIMS:

1. A method of an image enhancement as hereinbefore described and exemplified with reference to the accompanying drawings.

2. A Coherent Imaging system as hereinbefore described and exemplified with reference to the accompanying drawings.

3. A method of optical inspection as hereinbefore described and exemplified with reference to the accompanying drawings.

4. A system for optical inspection as hereinbefore described and exemplified with reference to the accompanying drawings.

Applicant

Moshe Finarov,

Director of Technology

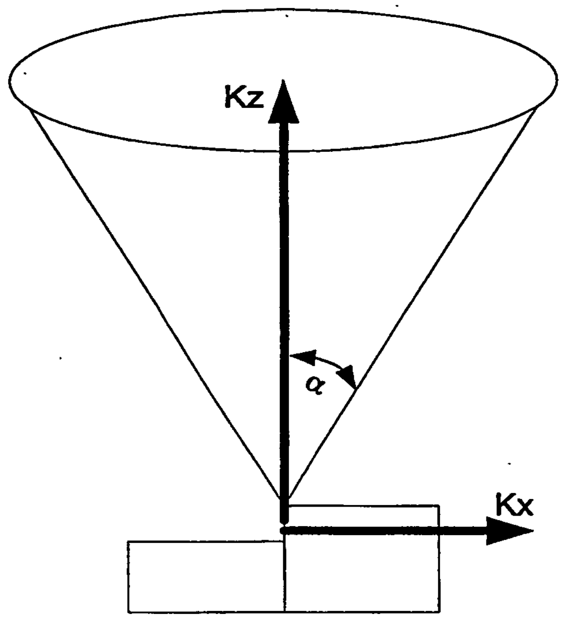


Fig. 1

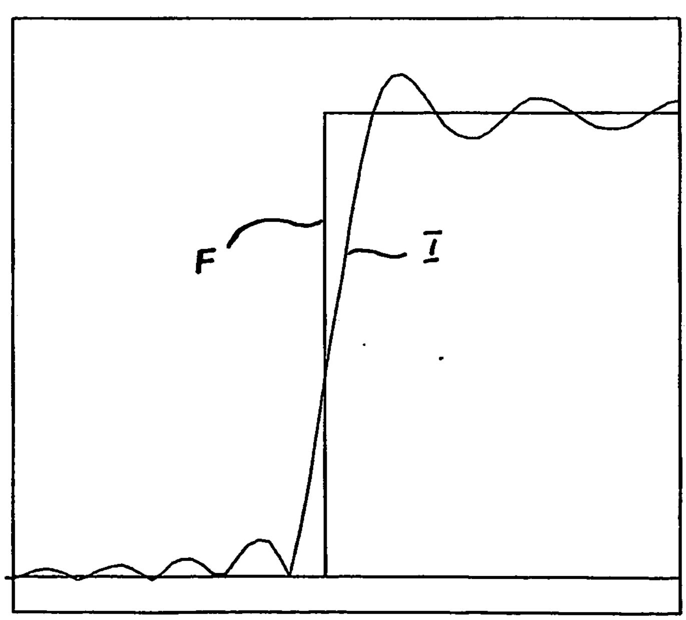


Fig. 2

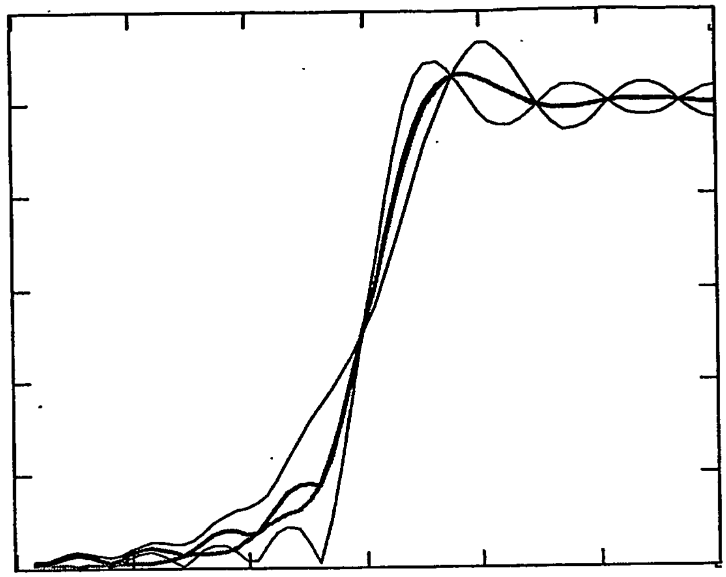
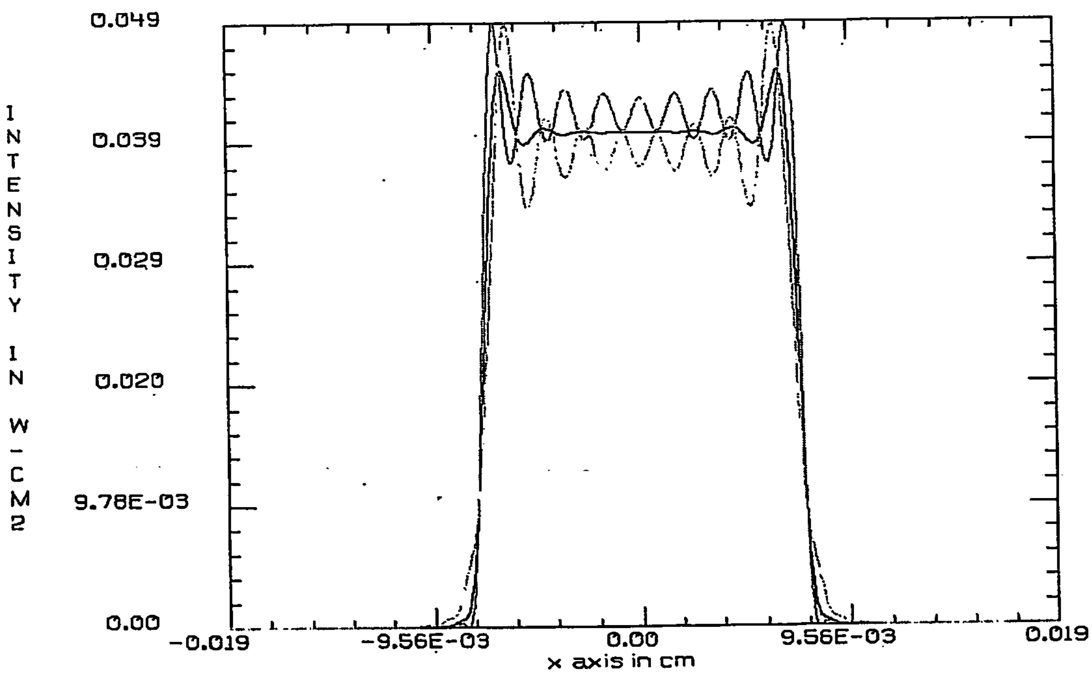


Fig. 3


0.049
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0.029
0.020
9.78E-03
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-9.56E-03
0.00
9.56E-03
0.019
x axis in cm

Fig. 4

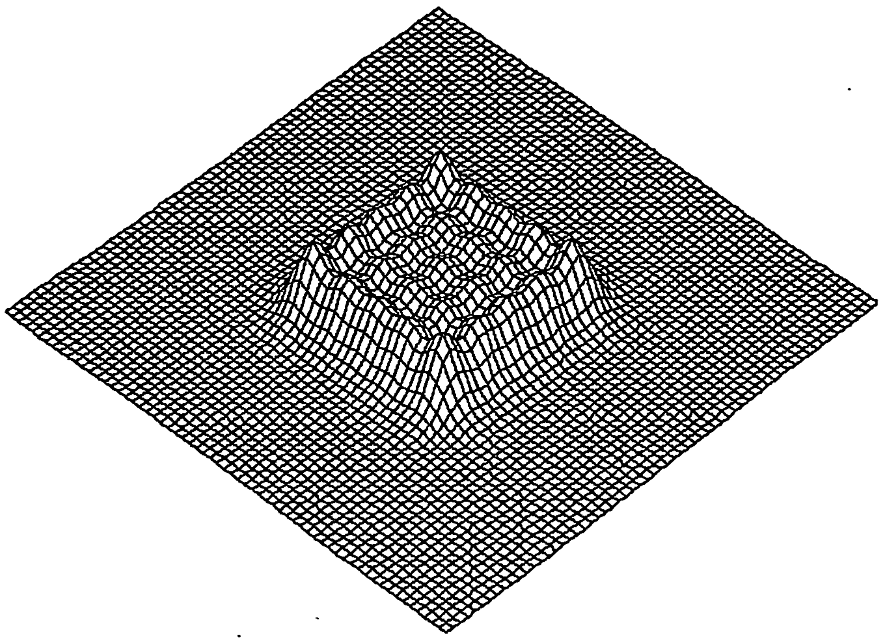

Fig. 5

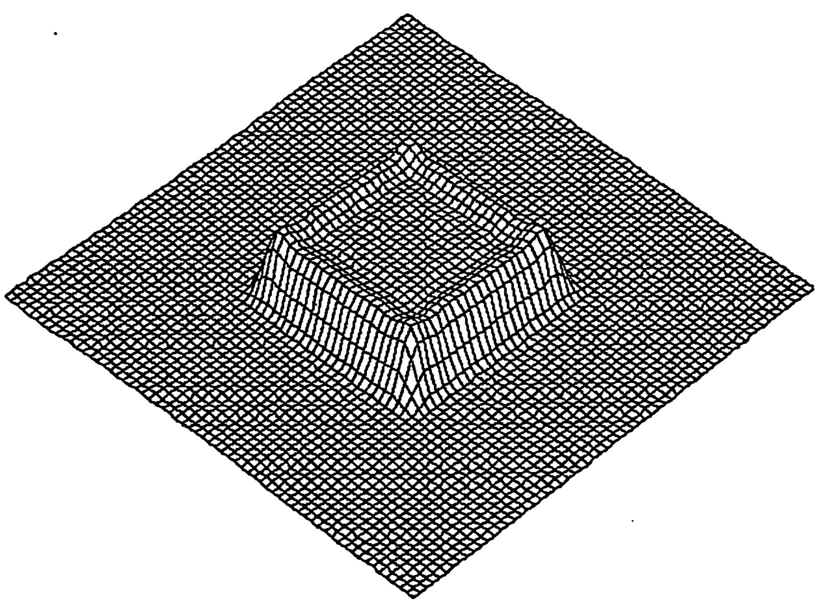

Fig. 6

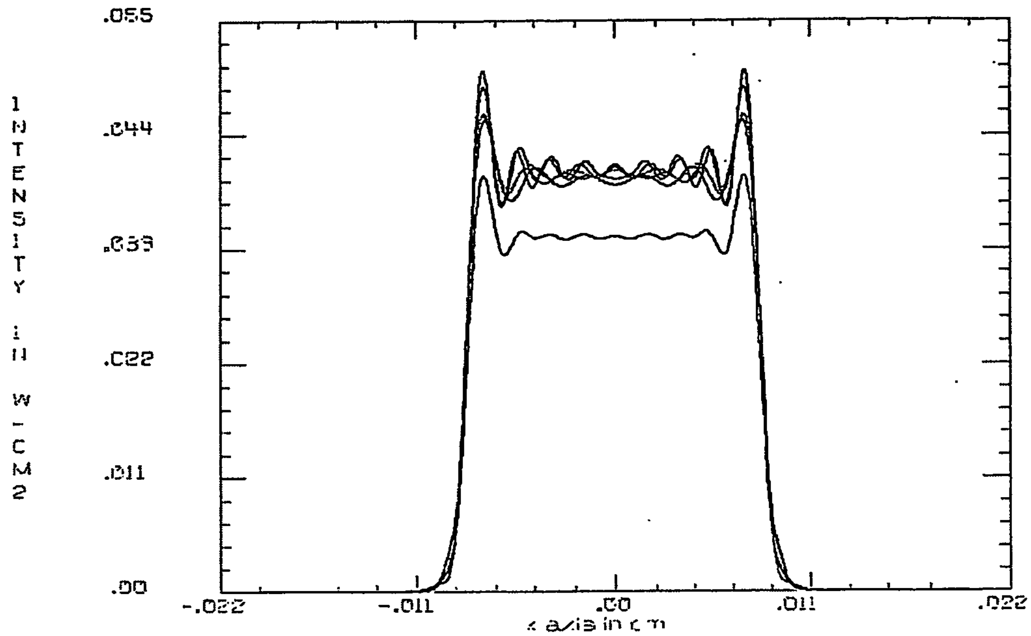

Fig. 7

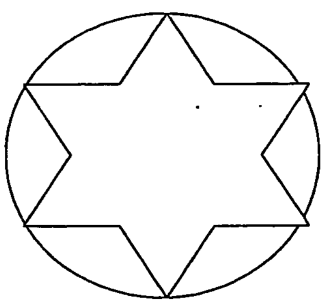

Fig. 8a

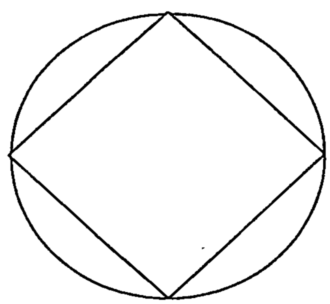

Fig. 8b